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Second Five-Year Review for the Lawrence Livermore National Laboratory Livermore Site

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September 2002

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Environmental Protection Department
Environmental Restoration Division

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Approval and Concurrence for the Second Five-Year Review for the Lawrence Livermore National Laboratory Livermore Site

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1. Introduction

This report documents the second five-year review period after finalizing the Record of Decision (ROD) in 1992 for the Lawrence Livermore National Laboratory (LLNL) Livermore Site. The first five-year review was completed in December 1997. This second five-year review evaluates whether the remedial actions defined in the ROD remain protective of public health and the environment and are functioning as designed. Incremental five-year reviews are required by policy because hazardous substances, pollutants, or contaminants still remain at the site above levels established by the regulatory agencies that allow for unlimited use and unrestricted exposure.

The LLNL Livermore Site ROD (U.S. Department of Energy [DOE], 1992) was signed in August 1992 by DOE and the U.S. Environmental Protection Agency (EPA). DOE is the lead agency for environmental restoration at LLNL. The lead regulatory agency for the Livermore Site is the EPA. In addition to the EPA, two California state agencies, the Regional Water Quality Control Board — San Francisco Bay Region (RWQCB), and the Department of Toxic Substances Control (DTSC), oversee the LLNL Livermore Site remediation and are parties to the Livermore Site Federal Facility Agreement (FFA).

This five-year review was conducted pursuant to Section 300.430(f)(4)(ii) of the National Oil and Hazardous Substance Pollution Contingency Plan (NCP), 40 Code of Federal Regulations (CFR) Part 300, which implements Section 121(c) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). This document format follows guidelines established by the EPA (EPA, 2001). The next five-year review will be due in 2007.

Although the current remedies are effectively working to achieve the Livermore Site remediation objectives, recommendations are discussed in Section 9 to further enhance remediation of the Livermore Site.

2. Site Chronology

Table 1 lists the chronology of major events for the Livermore Site relative to environmental restoration. Table 2 presents project restoration highlights since the first five-year review.

3. Background

Livermore Site characterization and history are briefly summarized in Sections 3.1 and 3.2. Complete site description, history, and characterization information was presented in the ROD, the Livermore Site Remedial Investigation Report (Thorpe et al., 1990), and the Feasibility Study (Isherwood et al., 1990).

3.1. Site Characteristics

The Livermore Site is a research and development facility owned by DOE and operated by the University of California, located approximately three miles east of downtown Livermore, California (Fig. 1). The Livermore Site comprises approximately 800 acres. The Diablo Range hills flank the site to the south and east, and the ground surface slopes down approximately 1% to the northwest. The site is underlain by several hundred feet of interbedded alluvial and lacustrine sediments.

Ground water beneath the site is partly within the Spring and Mocho I hydrologic subbasins (California Department of Water Resources, 1974). Depth to ground water at the site varies from about 130 feet (ft) in the southeast corner to about 25 ft in the northwest corner. Municipal wells about two miles west of the site supply water to downtown Livermore. Ground water south and west of the site is used for agricultural irrigation. Two intermittent streams, Arroyo Seco and Arroyo Las Positas, are located on the site and recharge the ground water during wet periods.

Land immediately north of the Livermore Site is zoned for industrial use. To the west, the land is zoned for high-density urban use. Sandia National Laboratories, California (SNL) is located south of the site. The area east of LLNL is zoned for agriculture and is currently used as pasture land (Thorpe et al., 1990).

3.2. Site History

The Livermore Site was converted from agricultural use by the U.S. Navy in 1942. The Navy used the site until 1946 as a flight training base and for aircraft assembly, repair, and overhaul. Solvents, paints, and degreasers were routinely used during this period. Between 1946 and 1950, the Navy housed the Reserve Training Command at the site. In 1950, the Navy allowed occupation of the site by the Atomic Energy Commission (AEC), which formally received transfer of the property in 1951. Under the AEC, the site became a weapons design and basic physics research laboratory. In 1952, the site was established as a separate part of the University of California Radiation Laboratory. Responsibility for the site was transferred to the Energy, Research, and Development Administration in 1975. In 1977, responsibility for LLNL was transferred to DOE for the foreseeable future.

Initial hazardous materials releases occurred at the Livermore Site in the mid- to late-1940s when the site was the Livermore Naval Air Station (Thorpe et al., 1990). There is also evidence that localized spills, unlined disposal pits and landfills, and leaking tanks and impoundments contributed volatile organic compounds (VOCs), fuel hydrocarbons (FHCs), metals, and tritium to the ground water and unsaturated sediments in the post-Navy era. The Livermore Site was placed on the EPA National Priorities List in 1987.

Compounds in ground water beneath the site at concentrations above drinking water standards are:

- VOCs—trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), chloroform, 1,2-dichloroethylene (1,2-DCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), trichlorofluoromethane (Freon 11), and carbon tetrachloride.

- FHCs—benzene, ethylbenzene, toluene, and ethylene dibromide.
- Metals—chromium.
- Radionuclides—tritium.

4. Remedial Actions

4.1. Remedy Selection

During the Remedial Investigation/Feasibility Study process, a number of assumptions were made to aid in the selection of the remedies considered for the ROD. The assumptions were based on information available at the time, and were expected to change with the addition of new data, wellfield performance, and unforeseen conditions. It was assumed that:

- Approximately 200 gallons (gal) of VOCs and 10,000 gal of FHCs needed to be remediated in the saturated zone.
- Approximately the liquid equivalent of 50 gal of VOCs and 1,000 gal of FHCs needed to be remediated in the unsaturated zone.
- Geological conditions consisted of an assortment of interlayered heterogeneous sediments.
- Releases were generally at the surface with multiple chemical signatures.
- Proven technologies existed and were available to remediate VOCs, metals, and FHCs in the saturated and unsaturated zones.
- Air stripping was the most effective technology for remediating VOCs and FHCs from ground water.
- Vacuum induced venting (vapor extraction) is the most effective technology for remediating VOCs and FHCs from the unsaturated zone.
- Cleanup of ground water to Maximum Contaminant Levels (MCLs) would take about 50 years.
- Dewatering may occur in areas of low permeability and/or aggressive pumping.
- Tritium would be kept in the subsurface as much as possible to self-remediate by natural decay, with no treatment.
- No significant new releases would be found.

After ten years of active remediation, most of the assumptions have been tested and performance is better than predicted. The following has been determined after ten years of gathering operational data:

- More VOC mass has been removed from ground water and the unsaturated zone than the original total estimate predicted.
- The quantity of FHCs extracted from the subsurface was close to the inventory predicted.

- Although heterogeneous, the subsurface is characterized by seven distinct hydrostratigraphic units (HSUs), each consisting of a unique assemblage of interconnected sediments that behave separate hydraulically from over- and underlying HSUs.
- The release sites were generally at the surface with multiple chemical signatures, but much more widespread and complex than envisioned.
- Proven technologies were available and utilized as appropriate; however, the development of a fleet of mobile portable treatment units were more productive, cost-effective and practical for remediation than the fixed treatment facilities agreed to in the ROD.
- Air stripping and vapor extraction proved to be the most effective technologies for overall remediation, although thermal technologies accelerated the remediation of FHCs by many years.
- Catalytic Reductive Dehalogenation (CRD) was an effective method to remediate VOCs co-mingled with tritium.
- Operational data indicates that total cleanup of the site to MCLs will take longer than the original simplistic estimate of about 50 years.
- Dewatering did occur in areas of low permeability and/or aggressive pumping and vapor extraction is an effective technology for remediating dewatered zones.
- Tritium does self-remediate by natural decay, with no treatment, when kept in the subsurface.
- New releases, and older unknown releases were discovered that added to the contaminant inventory and required remedial actions.

Twenty-seven ground water and two vapor extraction facilities are currently part of the remediation network (Fig. 2) used to meet the following remediation objectives for all contaminants originating at the Livermore Site:

- Prevent future human exposure to contaminated ground water and soil.
- Prevent further migration of contaminants in ground water.
- Reduce contaminant concentrations in ground water to levels below MCLs and reduce the contaminant concentrations in treated ground water to levels below state discharge limits.
- Prevent migration in the unsaturated zone of those contaminants that would result in concentrations in ground water above an MCL.
- Meet all existing permit discharge standards for treated water and soil vapor, and to treat vapor so that there are no measurable atmospheric releases from treatment systems.

The selected remedy in the ROD involved constructing seven ground water treatment facilities that used ultraviolet/oxidation-based remediation and/or air stripping. After installing four fixed treatment facilities, LLNL began constructing and installing less expensive portable ground water treatment units for use at more locations than were specified in the ROD. There are currently four types of portable ground water treatment units in use at LLNL (Fig. 3):

1. The Portable Treatment Unit (PTU), which uses air stripping to treat the ground water at a flow rate up to about 45 gallons per minute (gpm).
2. The Miniature Treatment Unit (MTU), which is a smaller version of the PTU that operates at about one-half the flow rate.
3. The Granular Activated-Carbon (GAC) Treatment Unit (GTU), which uses aqueous-phase GAC instead of air stripping to treat the ground water at a flow rate up to about 45 gpm.
4. The Solar-powered Treatment Unit (STU) also uses aqueous-phase GAC to treat the ground water at flow rates up to about 5 gpm but uses solar energy to operate the facility.

After a treatment unit has completed ground water cleanup at one location, it can be moved to another location; this increases cleanup flexibility and reduces capital costs. These portable treatment units, in conjunction with the fixed treatment facilities, serve as a network to effectively remediate onsite and offsite VOC ground water plumes. The selected remedy in the ROD for the unsaturated zone was soil vapor extraction and treatment. Soil vapor extraction is currently part of the cleanup strategy for the Trailer 5475 and Building 518 areas (VTF5475 and VTF518, respectively on Fig. 2), where high VOC concentrations exist in the unsaturated zone.

In addition to the treatment facility network discussed above, CRD is applied at locations where both tritium and VOCs are found co-mingled. Also, electro-osmosis (EO) was tested in a source area to help facilitate contaminant removal from the fine-grained sediments. Both technologies are discussed further in Section 5. All Livermore Site treatment technologies comply with Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) as defined in the ROD.

Four Explanations of Significant Differences (ESDs) have been prepared for changes to the remedies selected in the ROD. An ESD is required when significant, but not fundamental, changes are made to the final remedial action plan described in the ROD. The four ESDs were prepared for changing (1) catalytic oxidation to GAC for treatment of vapor at Treatment Facility F (TFF) (Dresen et al., 1993), (2) ultraviolet light/hydrogen peroxide (UV/H_2O_2) and air stripping remediation to air stripping only at Treatment Facilities A and B (TFA and TFB) (Berg et al., 1997a), (3) discharge requirements for metals based on wet season and dry season beneficial use (Berg et al., 1997b), and (4) the remedy to allow ground water containing both VOCs and tritium to be brought to the surface via a closed-loop treatment system to remediate the VOCs, and returning the tritiated water to the subsurface to decay naturally (Berg, 2000).

4.2. Remedy Implementation

During the first five-year review, the remedial actions were found to be functioning as intended. Since 1989, 29 ground water and three soil vapor treatment facilities have been operated at various locations. However, one ground water and one soil vapor treatment facility were shut down after fuel hydrocarbon cleanup was completed at TFF (in the TF406 area), and one portable ground water facility was relocated elsewhere at the Livermore Site due to dewatering in the TF518 area (Fig. 2). Currently, 27 ground water and two vapor facilities are part of the remediation network (Fig. 2). The current remediation network continues to function as intended and is protective of human health and the environment. DOE/LLNL are actively working toward completing the remediation system build-out as quickly as possible to reduce long-term operational costs and accelerate the time to cleanup. Table 3 presents the remaining construction milestones as agreed upon by DOE and the regulatory agencies in the March 2001 Remedial Action Implementation Plan milestone list.

VOC concentration and distribution trends since the first five-year review are discussed in Section 6.3.2. Figures 4 and 5 present VOC isoconcentration maps for Hydrostratigraphic Units 1B and 2, respectively, in 1992, 1997, and 2002.

4.3. System Operation

Table 4 presents the status and performance of each treatment facility through March 2002. The Livermore Site consists of a single operable unit, but is subdivided into nine treatment facility (TF) areas. All facilities are performing as designed to remediate ground water or soil vapor; however, subsurface conditions, such as dewatering or perched water-bearing zones (discussed further in Section 6.3.1) have affected the effectiveness of some facilities. Issues requiring system modifications since the first five-year review are presented in Table 5, as well as the resultant resolutions and/or lessons learned.

4.4. Operations and Maintenance

Facility Operations and Maintenance (O&M) requirements include mechanical O&M, control and instrument calibration, and facility documentation and data collection.

Facility O&M procedures are contained in the Remedial Design documents and the facility O&M Maintenance Manuals, and are consistent with the RWQCB and Bay Area Air Quality Management District requirements.

Average annual O&M costs per unit are about $225,000 for a fixed facility, $68,000 for a PTU, $68,000 for a MTU, $59,000 for a GTU, $42,000 for a STU, $190,000 for a CRD, and $39,000 for a soil vapor treatment unit. On average, the overall O&M cost to maintain the existing treatment facilities is about $8–9M annually. Total project funding authorized by DOE during 1997–2002 for cleanup at the Livermore Site is presented in Table 6.

4.5. Administrative and Institutional Controls

The following administrative controls and institutional controls are already in place at the Livermore Site and are expected to be maintained for the predictable future: access is restricted and controlled by fencing and a full-time security force; building occupancy and land use is controlled by the Livermore Site management; additional access controls are enforced in areas outside of regular work areas; a safety briefing, which covers access requirements and areas of contamination, is required by all personnel working at the Livermore Site; there are no drinking water wells on the site, and any new water-supply wells of any kind are subject to review with environmental consideration in mind; and Operational Safety Plans are required for all construction activities, including checks for hazardous materials and sensitive species.

Performing remedial actions, posting of signs, and ongoing surveillance/maintenance programs also comprise the current and anticipated long-term institutional controls.

5. Progress Since the First Five-Year Review

No corrective actions were noted during the first five-year review. Since the first five-year review, 17 ground water treatment facilities and one soil vapor extraction system have been added to the remediation network (Table 4). Also since the first five-year review, two new technologies, CRD and EO, have been applied to ground water cleanup, and two removal actions were conducted.

CRD technology was developed at LLNL in conjunction with Stanford University to treat VOCs that are mixed with tritium in the ground water in the Trailer 5475 area (TF5475-1 and TF5475-3 on Fig. 2). The CRD treatment method utilizes dissolved hydrogen in the presence of a palladium catalyst to chemically reduce chlorinated VOCs into methane, ethane, and ethene. This treatment method does not treat tritium, but as stated in the ROD, the remedial approach is to keep tritium in the subsurface as much as possible where it will decay naturally. Therefore, after VOC removal, the water containing tritium is returned to the subsurface. The first CRD unit was deployed downhole in September 1998 (Fig. 6) and the second CRD unit was deployed above ground using a closed-loop system in September 2000 (Fig. 7); both units are operating as designed.

Electro-osmosis was tested September 2000 to February 2001 to help facilitate VOC removal from fine-grained sediments in a source area near the Helipad (TFD area; Fig. 2). To implement electro-osmosis, a direct current is passed between electrodes to induce the flow of water in fine-grained sediments from an anode (positive electrode) to a cathode (negative electrode). At the Helipad site, a nine-well array (a square grid of three wells by three wells) was constructed with three cathode wells in the center and the anode wells on each side (Fig. 8). Ground water was extracted at the cathode wells and treated at a Portable Treatment Unit (PTU-10; Fig. 2). Results from this test indicated an increase in mass removal when electro-osmosis was deployed, but additional testing is required to determine if this technology is appropriate and cost effective.

Two removal actions were conducted to eliminate potential exposure pathways and to protect human health and the environment. The first removal action removed and disposed of 112 buried capacitors and about 766 tons of soil containing polychlorinated biphenyls (PCBs) by a regulatory-approved Emergency Removal Action at the National Ignition Facility (NIF) construction site (Fig. 2) in September 1997. The Action Memorandum for this removal action was finalized in February 1998 (Bainer and Berg, 1998). Subsequent to the capacitor removal, skeletal remains of a mammoth were discovered during construction excavation. LLNL's Environmental Restoration Division led the effort to excavate and preserve the mammoth bones. The second removal action removed and disposed of about 400 cubic yards of soil from the East Traffic Circle (Fig. 2) that contained residual PCBs from a nearby landfill excavation. This removal action began in January 1999 and was completed in July 1999. The Action Memorandum for this removal action was finalized in March 2000 (Joma, 2000). No additional action was recommended for either removal action.

6. Second Five-Year Review Process

This five-year review consisted of examining relevant project documents and site data. A notice informing the public that this five-year review was in progress was placed in the Valley Times, Tri-Valley Herald, and The Independent newspapers in April 2002. Project documents are available in the information repositories at the LLNL Visitor's Center and the Livermore Library. Most project documents can also be accessed electronically at LLNL's Environmental Restoration Division electronic library web page at http://www-erd/library/, the Environmental Community Relations web page at http://www-envirinfo.llnl.gov/, or LLNL's Technical Information Department's external document web page at http://www.llnl.gov/tid/lof/.

DOE is responsible for the communications with the public regarding its environmental remediation efforts at the Livermore Site. These include interactive components to encourage public participation and comments on the direction of site remediation activities. The Livermore Site has a Community Work Group that reviews and comments on the remediation priorities and a Technical Assistance Grant group that comments regularly on all draft documents. There is a communication process that encourages public participation through newsletters, mailings directed to immediate neighbors and, when appropriate, public notices. The notices and letters frequently include a request for public comment on the communications. Correspondences direct the interested parties to the Environmental Community Relations web page that provides information on environmental remediation efforts. LLNL employees and site workers receive information through similar media, in addition to the Laboratory print and on-line newspapers; many employees and site workers live nearby and are included in the offsite communications, as are many retirees. Past public opinion surveys show a high acceptance by the public of DOE's environmental remediation efforts. Comments from individual public members and the Technical Assistance Grant participant support this finding.

6.1. Interviews and Site Inspection

Interviews or site inspection are not required because DOE, the lead agency, with oversight from EPA, RWQCB, and DTSC have an ongoing presence and are involved with, and are knowledgeable of site activities, issues, concerns, and status (EPA, 2001).

6.2. Risk Information Review

There have been no changes in location-, chemical- or action-specific requirements that would affect the remedies, or in exposure pathways, toxicity, and other contaminant characteristics since the ROD.

The screening conducted for the Baseline Public Health Assessment (BPHA) (Layton et al., 1990) considered all potential exposure pathways and concluded that ground water is the only viable pathway of exposure, and the inhalation risk from VOCs migrating from ground water to the breathing zone is insignificant. Although there have been isolated new discoveries of sources, they are all within areas evaluated for the BPHA and/or have been excavated, eliminating the risk of exposure. In addition, soil vapor surveys were conducted throughout the Livermore Site during the Remedial Investigation, again indicating that the risk of exposure to VOCs through the inhalation pathway is insignificant.

In addition, studies were conducted in 1991 to evaluate the VOC inhalation risk to building occupants. Five trailers were selected for this study in areas identified as containing the highest concentrations of VOCs onsite, both in the unsaturated zone and the ground water. Ambient air samples were collected beneath and around these trailers. Analytical results indicated that only very low concentrations (less than 5 parts per billion [ppb] by volume) of VOCs were detected beneath and around the trailers. Virtually no difference was noted between samples collected beneath the trailers and samples collected outside in the open air. No VOCs were detected in any of the samples in concentrations near the Permissible Exposure Limit, which would be considered a health risk at LLNL The results from this investigation corroborated previous studies that concluded volatilization of VOCs from the unsaturated zone do not present a health risk at LLNL.

Nonetheless, air monitoring stations are located surrounding and throughout LLNL and the Livermore Valley, results of which are published yearly in the Site Annual Environmental Report. Specific air monitoring events are conducted in areas of concern, particularly if surficial sediments are removed during drilling or excavation activities.

6.3. Data Review and Findings

Through March 2002, approximately 1.8 billion gallons of ground water and over 34 million cubic feet of soil vapor have been treated since the onset of site cleanup in 1989, removing about 1,300 kilograms (kg) (2,866 pounds) of VOCs. This represents more than a three-fold increase in VOC mass removal since the first five-year review. This increase in mass removal has occurred due to focusing on cleanup of high concentration areas in the eastern part of the site. Figure 9 presents VOC mass removal in ground water and soil vapor from 1989 through 2001.

Monthly self-monitoring data show that the treatment facilities are removing contaminants from ground water and soil vapor, and treating the contaminants to concentrations below discharge levels. Adherence to substantive requirements has been consistent over the last five years with infrequent incidents promptly reported and corrected.

Ground water concentration data indicates that contaminant concentrations, mass, and areal extent continue to be reduced, as discussed further in Section 6.3.2. Ground water elevation contours indicate that there is hydraulic capture of the western and southern margin plumes (Dibley et al., 2002).

6.3.1. Information and Lessons Learned Since the First Five-Year Review

As discussed below, ongoing cleanup strategies and new information learned since the first five-year review has helped cleanup efficiency as well as refine cleanup needs.

<u>Effective cleanup strategy</u>: As described in the first Five-Year Review document, DOE/LLNL developed the Hydrostratigraphic Unit and Engineered Plume Collapse (EPC) strategies to more effectively clean up ground water contamination. These strategies continue to enhance cleanup at the Livermore Site. Hydrostratigraphic unit analysis integrates chemical, hydraulic, geophysical, and geological data into a detailed three-dimensional model of the subsurface. Through this analysis, the heterogeneity of the Livermore Site subsurface can be subdivided into discrete and distinct hydrostratigraphic units (Fig. 10) that allow DOE/LLNL to correlate contaminant plumes to individual source areas and gain a better understanding of

contaminant transport and distribution. This has allowed DOE/LLNL to target individual contaminant plumes, place extraction wells at optimum locations to meet cleanup objectives faster, and conduct a comprehensive and more cost-effective cleanup.

The EPC strategy first targets and hydraulically isolates the source areas to allow rapid distal plume cleanup. This is followed by applying conventional and advanced technologies to cleanup contaminated fine-grained source area sediments. As discussed in Section 5 of this Five-Year Review, an advanced technology, electro-osmosis, was tested and indicated an increase in VOC removal from the source area near the Treatment Facility D Helipad. As discussed further in Section 6.3.2, EPC has facilitated a significant decrease in the size and concentration of contaminant plumes over the last five years, especially in critical areas such as the western boundary and offsite plumes.

Improved facility operation: DOE/LLNL have also learned how to be more effective in reducing cost, manpower, and downtime of the treatment facilities. Some of these improvements include switching from ultraviolet oxidation systems to high-capacity air strippers, mitigating bioaccumulation on the CRD units, reducing facility downtime for air stripper maintenance, and improving longevity of the treatment units to include the air stripping tanks, blowers, and control systems. These lessons learned are described further in Table 5.

Stagnation point: The existing treatment facilities have hydraulic control of the western margin, although there may be a stagnation point downgradient of Treatment Facility A. Isoconcentration contour maps (Fig. 5) show the offsite plume stagnation point beneath the residential area. Dynamic wellfield management, such as increasing flow rates on nearby extraction wells, may eliminate this stagnation point with time, but if this stagnation point remains in this location, ground water extraction from monitor well(s) may be considered.

Recharge Basin percolation: Treatment Facility A treats ground water in the southwestern corner of the site and discharges the treated water into the Recharge Basin to the south (Fig. 2). Treatment Facility A is the primary treatment facility for capturing and treating the offsite plumes under nearby residential neighborhoods. Poor percolation in the Recharge Basin has resulted in reduced Treatment Facility A operation and offsite plume cleanup. Normal maintenance of the Recharge Basin includes removing vegetation and tilling of the bottom of the cells. Over time, a significant reduction in percolation occurs even after periodic maintenance.

Ground water mounding: Ground water mounding beneath the Recharge Basin has caused the ground water gradient to shift, resulting in incomplete capture of contaminants in the Treatment Facility A source area. An additional treatment unit in the Treatment Facility A source area may be needed to remediate any contaminants not captured due to ground water mounding. Alternatively, discharging less water to the Recharge Basin by diverting some or all of the treated water to other locations is currently being evaluated. If treated water from Treatment Facility A is not diverted from the Recharge Basin, DOE/LLNL will examine the possibility of excavating soil from the bottom of the Recharge Basin cells to help improve the percolation efficiency.

Trailer 5475 contaminant source: While drilling in the Trailer 5475 area, contamination was discovered in a deeper zone (Hydrostratigraphic Unit-5). Once identified, this deeper contamination began being treated in September 2001.

Building 518 contaminant source: A new contaminant source may exist in the Treatment Facility 518 area (TF518 on Fig. 2). Soil vapor extraction flow at vapor Treatment Facility 518 had notably decreased over time due to the saturation of shallower sediments. It is suspected that above-average rainfall during the late 1990s regenerated a perched water-bearing zone, which had been previously observed in the 1980s. Total VOC concentrations in this regenerated perched zone initially exceeded 80,000 ppb, which is the highest VOC concentrations detected at the site. Concentrations in the perched zone are currently about 14,000 ppb. The source(s) of these high VOC concentrations are unknown, requiring further characterization and potentially additional remediation activities. No adverse impacts to the deeper ground water from this regenerated perched zone have been observed. The elevated soil moisture content has impeded effective vadose zone cleanup in this area; however, continued soil vapor extraction induces movement of the perched water for extraction and treatment. Currently the vapor treatment facility, VTF518 (Fig. 2), is shut down for refurbishing or possible replacement. Vapor extraction is expected to be back in operation before the end of 2002.

Dewatering: One issue affecting rapid ground water cleanup is dewatering of various hydrostratigraphic units, primarily in the southeastern portion of the Livermore Site. Since 1992, water levels in Hydrostratigraphic Unit-5 have decreased as much as 40 ft; Hydrostratigraphic Units-3A, -3B, and -4 have decreased up to 26 ft; and Hydrostratigraphic Unit-2 has decreased up to 8 ft. Dewatering can adversely affect the ground water gradient, reduce mass removal due to lower sustainable flow rates, and result in inefficient treatment facility operation. Reinjection of clean water into the subsurface may be required to complete clean up of contaminants in dewatered portions of the Livermore Site. Certain dewatered source areas, such as the Trailer 5475 area, may benefit more from soil vapor extraction rather than reinjection.

6.3.2. Trends in Chemical Concentrations and Extent

Chemical trends were compared over a five-year timeframe (1996 to 2001) to evaluate the cleanup progress for this five-year review. Since the first five-year review, the size and concentration of contaminant plumes at the Livermore Site have decreased significantly in areas where ground water extraction and treatment have been implemented. The following summarizes some key points of this trend analysis. A more in-depth trend discussion is included in the Livermore Site Ground Water Project 2001 Annual Report (Dibley et al., 2002). Treatment facilities are identified on Figure 2.

Western boundary (Treatment Facility A and Treatment Facility B areas) five-year trends include:

- A 66% mass decrease in the Hydrostratigraphic Unit-1B offsite plume, with most now being below MCLs.
- A 48% mass decrease in the Hydrostratigraphic Unit-2 offsite plume.
- Onsite concentrations reduced below MCLs in Hydrostratigraphic Units-1B and -2 in the area south of Treatment Facility A.
- Concentrations reduced below MCLs in the offsite Hydrostratigraphic Unit-3A plume.
- Two orders of magnitude decrease of onsite PCE concentrations in the Treatment Facility A source area.

Site interior and southern boundary five-year trends include:

- An order of magnitude reduction in Hydrostratigraphic Unit-2 TCE concentrations in the Treatment Facility D area.
- Elimination of Hydrostratigraphic Unit-4 TCE concentrations exceeding 500 ppb in the western Treatment Facility D and northern Treatment Facility E areas, and an 80% reduction in the area where TCE concentrations exceed 100 ppb.
- Little change in a large, low-concentration Hydrostratigraphic Unit-2 TCE plume centered around the West Traffic Circle in the Treatment Facility C area (Fig. 2). This plume is now being remediated by the TFC-E facility installed in April 2002.
- Westward migration of an Hydrostratigraphic Unit-2 plume in the western Treatment Facility E area into a restricted access area. Recently installed treatment facility TFE-W, in conjunction with a proposed facility north of TFG-1, are expected to hydraulically contain and remediate this plume.
- Nearly complete cleanup in Hydrostratigraphic Unit-2 in the TFG-1 area.
- Elimination of VOC concentrations exceeding 50 ppb in the Hydrostratigraphic Unit-5 southern offsite plume.
- Completion of Hydrostratigraphic Unit-4 ground water cleanup in the southern Treatment Facility 406 area.

Well locations that have completed ground water cleanup to concentrations below MCLs are being monitored following the Compliance Monitoring Plan (Nichols et al., 1996).

Based on data collected over the last five years, new estimates of the remaining mass and pore volumes of VOCs exceeding 5 ppb remaining in the subsurface were calculated for each hydrostratigraphic unit (Table 7).

7. Technical Assessment

The following conclusions support the determination that the remedy is functioning as intended and is protective of human health and the environment:

- The Health and Safety Plan and Contingency Plan are in place, properly implemented, and are sufficient to control risks.
- All required institutional controls are in place and any current or planned changes in land use at the site suggest that they would continue to be effective.
- Ground water and soil vapor extraction and treatment will effectively control contaminant migration and reduce the contaminant concentration and areal extent.
- The ground water remedial actions continue to be effective in reducing contaminant mass and extent.
- Treatment facilities are operating as designed and in a manner consistent with requirements.
- No early indicators of potential remedy failure were noted in this five-year review.

- There have been no changes in location-, chemical- or action-specific requirements; exposure pathways, toxicity, and other contaminant characteristics; or changes in risk assessment methodologies that would invalidate the remedy selection.
- No other information has been identified that could call into question the protectiveness of the remedy.

8. Issues

As discussed in Section 6.3.1, the following issues require further evaluation:

- An unidentified contaminant source in the Building 518 area.
- Dewatering, primarily in the southeastern part of the Livermore Site.
- A potential stagnation point downgradient of Treatment Facility A.
- Treatment Facility A not operating at capacity due to discharge limitations.

In addition, more detailed characterization of source areas is needed to determine how sources influence remediation efforts and affect predictive models. Although electro-osmosis appears to increase mass removal from the source areas, the field testing was limited in duration. Additional testing is needed to determine if this technology is technically appropriate and cost effective for cleanup of the Livermore Site source areas. Other remedial technologies may need to be evaluated for source area cleanup.

9. Recommendations and Follow-up Actions

The following recommendations were developed by DOE/LLNL during the five-year review process:

- Characterize the source of high VOC concentrations in the Building 518 perched water-bearing zone.
- Evaluate reinjection and/or vapor extraction for dewatered locations.
- Continue to monitor the potential stagnation point downgradient of Treatment Facility A to determine if ground water extraction is needed at this location.
- Continue to characterize the source areas and further evaluate source area remediation technologies.
- Complete the remediation system build-out as soon as possible.
- Evaluate treated water disposal options at Treatment Facility A.

10. Protectiveness Statement

The remedy is functioning as intended and is protective of human health and the environment. Both the Health and Safety Plan and Contingency Plan are in place, properly implemented, and are sufficient to control risks. DOE/LLNL are actively working toward completing the remediation system build-out as quickly as possible to reduce long-term operational costs and accelerate the time to cleanup. DOE/LLNL are committed to the Livermore Site remediation objectives of (1) preventing present day and future human exposure to contaminated ground water and soil, (2) preventing contaminant migration, (3) reducing contaminant concentrations in ground water to levels below the state and federal MCLs, and (4) minimizing contaminant migration in the unsaturated zone that would result in concentrations in ground water above a MCL.

11. Next Review

The next review will be conducted in 2007, within five years of the completion of this five-year review.

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13. Acronyms and Abbreviations

1,1-DCA	1,1-dichloroethane
1,2-DCA	1,2-dichloroethane
1,1-DCE	1,1-dichloroethylene
1,2-DCE	1,2-dichloroethylene
AEC	Atomic Energy Commission
ARAR	Applicable or Relevant and Appropriate Requirement
BPHA	Baseline Public Health Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CRD	Catalytic Reductive Dehalogenation
DOE	U.S. Department of Energy
DTSC	California Department of Toxic Substances Control
EO	Electro-osmosis
EPA	U.S. Environmental Protection Agency
EPC	Engineered Plume Collapse
ESD	Explanation of Significant Differences
FFA	Federal Facility Agreement
FHC	fuel hydrocarbon
Freon 11	trichlorofluoromethane
ft	feet
gal	gallon
gpm	gallons per minute
GAC	Granular Activated Carbon
GTU	GAC Treatment Unit
HSU	Hydrostratigraphic Unit
kft^3	thousands of cubic feet
kg	kilograms
LLNL	Lawrence Livermore National Laboratory
MCL	Maximum Contaminant Level

Mft^3	millions of cubic feet
Mgal	millions of gallons
MTU	Miniature Treatment Unit
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NIF	National Ignition Facility
O&M	Operations and Maintenance
PCB	polychlorinated biphenyl
PCE	perchloroethylene
ppb	parts per billion
PTU	Portable Treatment Unit
ROD	Record of Decision
RWQCB	California Regional Water Quality Control Board—San Francisco Bay Region
SARA	Superfund Amendments and Reauthorization Act
SNL	Sandia National Laboratories
STU	Solar Treatment Unit
TCE	trichloroethylene
TF	Treatment Facility
TF406	Treatment Facility 406
TF5475	Treatment Facility 5475
TF518	Treatment Facility 518
TFA	Treatment Facility A
TFB	Treatment Facility B
TFC	Treatment Facility C
TFD	Treatment Facility D
TFE	Treatment Facility E
TFF	Treatment Facility F
TFG	Treatment Facility G
UV/H_2O_2	ultraviolet light/hydrogen peroxide
VOC	volatile organic compound
VTF518	Vapor Treatment Facility 518
VTF5475	Vapor Treatment Facility 5475
Y2K	Year 2000

Tables

Table 1. Livermore Site chronology of events.

Date	Event
1942–1949	Site used as U.S. Navy Air Station; first release of hazardous materials
1950s	Undocumented releases of radioactive and hazardous materials to soil
1960s	Landfills, evaporation ponds, and disposal pits constructed
1970s	DOE/LLNL began environmental investigations
1982–1983	Excavation of four disposal pits containing debris, and disposed of about 3,000 cubic yards of contaminated soil containing volatile organic compounds and radionuclides from the East Taxi Strip area
1983	DOE/LLNL discovers ground water contamination on- and off-site and notifies regulatory agencies
1984–1985	Excavation and removal of about 14,000 cubic yards of soil and debris, and 160 buried capacitors from the East Traffic Circle Landfill
1987	Livermore Site named to the National Priorities List (Superfund)
1988	Federal Facility Agreement signed by DOE and regulatory agencies
1989	DOE/LLNL established Community Work Group
1989	DOE/LLNL initiated the Remedial Investigation
1992	Record of Decision signed determining scope and remedies of cleanup
1993	Completed Explanation of Significant Differences for a change in the vapor treatment at Treatment Facility F
1994	LLNL developed hydrostratigraphic unit analysis for more effective cleanup
1995	State closure of Treatment Facility F vadose zone cleanup
1995	DOE/LLNL achieved hydraulic control of contaminated plumes at the western site boundary
1996	State "No Further Action" for the Treatment Facility F fuel hydrocarbon contamination
1996	DOE/LLNL implemented Engineered Plume Collapse strategy using portable treatment units
1997	First five-year review concluded cleanup ahead of schedule
1997	Removed about 766 tons of contaminated soil and 112 buried capacitors containing polychlorinated biphenyls at the site of the National Ignition Facility
1997	Completed Explanation of Significant Differences for a change in the ground water treatment at Treatment Facilities A and B
1997	Completed Explanation of Significant Differences for a change in metals discharge requirements
1999	Removed over 400 cubic yards of residual contaminated soil containing polychlorinated biphenyls at the East Traffic Circle
2000	Completed Explanation of Significant Differences for a design change for Treatment Facility 5475
2002	Second five-year review concluded remedy is functioning as intended and is protective of human health and the environment

Table 2. Project highlights since the first five-year review.

Date	Event
September 1997	Completed an emergency removal action for contaminated soil and 112 buried capacitors containing polychlorinated biphenyls at the site of the National Ignition Facility
October 1997	Received regulatory approval for low-volume purge of monitor wells
December 1997	Issued a closeout report for the emergency removal action at the National Ignition Facility site
December 1997	Participated in removing and preserving mammoth bones from the National Ignition Facility site
December 1997	Received regulatory approval to increase Treatment Facility A discharge from 350 to 500 gallons per minute
1997–1998	Updated the Standard Operating Procedures and the Quality Assurance Project Plan to EPA's specifications
1998	Conducted magnetic surveys, ground penetrating radar surveys, borehole drilling, excavation, and induced electrical conductivity surveys within the National Ignition Facility stipulated area as part of a legal settlement
January 1998	Started treatability testing of aqueous-phase granular activated carbon
January 1998	Started operation of ground water Treatment Facility 518
February 1998	Completed Remedial Design Report No. 4 for the Trailer 5475 area
February 1998	Finalized an Action Memorandum for the National Ignition Facility emergency removal action
March 1998	Received regulatory approval to implement the revised guard well sampling plan
March 1998	Started operation of ground water Treatment Facility D Southeast
June 1998	Started operation of ground water Treatment Facility E Northwest
September 1998	Completed soil sample collection at Big Trees Park (west of LLNL) that showed no unacceptable risk from plutonium concentrations in the soil
September 1998	Started operation of ground water Treatment Facility 5475-1 (catalytic reductive dehalogenation unit 1)
October 1998	Replaced ultraviolet oxidation system at Treatment Facility B with high-capacity air stripper
January 1999	Started operation of vapor Treatment Facility 5475
March 1999	Started operation of ground water Treatment Facility 5475-2
July 1999	Completed removal action for over 400 cubic yards of contaminated soil containing polychlorinated biphenyls in the East Traffic Circle
June 1999	Started operation of ground water Treatment Facility D South
September 1999	Completed a rebound test of Hydrostratigraphic Unit 5 in the southeast corner of the Livermore Site

Table 2. Project highlights since the first five-year review (Cont. Page 2 of 2).

Date	Event
July 1999	Cumulatively treated over 1 billion gallons of contaminated ground water
August 1999	Started operation of a solar treatment unit in the Treatment Facility A area
December 1999	Completed facility software upgrades to be Year 2000 (Y2K) compliant
January 2000	Discovered volatile organic compound and tritium contamination in Hydrostratigraphic Unit 5 in the Trailer 5475 area
January 2000	Discovered standing water in vadose zone wells in the Treatment Facility 518 area
January 2000	Started operation of ground water Treatment Facility 518 North
February 2000	Completed Explanation of Significant Differences for a design change for Treatment Facility 5475
March 2000	Finalized the Action Memorandum for the East Traffic Circle time-critical removal action
April 2000	Received regulatory approval to reduce sampling for fuel hydrocarbons in the Treatment Facility F area
June 2000	Started operation of ground water Treatment Facility E Southwest
June 2000	Started operation of ground water Treatment Facility D Southshore
June 2000	Deployed Savannah River Site's Purge Water Management Systems in three wells
July 2000	Cumulatively removed over 1 ton of volatile organic compounds from the subsurface
July 2000	Confirmed high concentrations of volatile organic compounds in perched water in the Building 518 area vadose zone
August 2000	Deployed Savannah River Site's Tool Box (nonaqueous-phase liquid sampler) in the Building 518 area
September 2000	Started operation of the electro-osmosis system at Treatment Facility D Helipad
September 2000	Started operation of ground water Treatment Facility 5475-3 (catalytic reductive dehalogenation unit 2)
March 2001	Started operation of ground water Treatment Facility E Southeast
April 2001	Started operation of ground water Treatment Facility E West
July 2001	Started operation of ground water Treatment Facility D Marina Pipeline
September 2001	Started operation of catalytic reductive dehalogenation Phase 3 at Treatment Facility 5475-3
April 2002	Started operation of ground water Treatment Facility C East

Table 3. Construction milestone schedule.

Task	Completion date
Begin Operation of Treatment Facility G North	1-31-03
Begin Operation of Treatment Facility C Northeast	5-30-03
Begin East Taxi Strip Source Area Remediation	9-26-03
Begin Operation of Treatment Facility 406 South	1-30-04
Begin Southern East Traffic Circle Source Area Remediation	5-28-04
Begin Treatment Facility D Hotspot Remediation	9-30-04
Begin Helipad Source Area Remediation	1-28-05
Begin Treatment Facility E Hotspot Remediation	3-31-05
Begin Northern East Traffic Circle Source Area Remediation	6-30-05
Begin Treatment Facility 406 Hotspot Remediation	9-30-05
Begin Building 419 Source Area Remediation	1-27-06
Begin Treatment Facility B/C Hotspot Remediation	5-31-06
Begin Buildings 511/514 Source Area Remediation	9-29-06

Table 4. Livermore Site treatment facility summary.

Facility[a]	Media treated	Contaminants	Facility type	Technologies	Operating dates	Volume treated[b]	Mass removed[b]
TFA	Ground water	VOCs	Fixed	Air stripping with granular activated carbon (GAC)	April 1989 – present	951 Mgal	144 kg
TFA East	Ground water	VOCs	STU	GAC	August 1999 – present	1.06 Mgal	0.61 kg
TFB	Ground water	VOCs; hexavalent chromium	Fixed	Air stripping with GAC; ion exchange	July 1990 – present	185 Mgal	53.8 kg
TFC	Ground water	VOCs; hexavalent chromium	Fixed	Air stripping with GAC; ion exchange	October 1993 – present	127 Mgal	43.3 kg
TFC Southeast	Ground water	VOCs; hexavalent chromium	PTU	Air stripping with GAC; ion exchange	January 1997 – present	17.9 Mgal	6.06 kg
TFC East	Ground water	VOCs; hexavalent chromium	MTU	Air stripping with GAC; ion exchange	April 2002 – present	N/A	N/A
TFD	Ground water	VOCs	Fixed	Air stripping with GAC	September 1994 – present	164 Mgal	177 kg
TFD West	Ground water	VOCs	PTU	Air stripping with GAC	April 1997 – present	44.2 Mgal	21.5 kg
TFD East	Ground water	VOCs	PTU	Air stripping with GAC	September 1997 – present	31.4 Mgal	44.9 kg
TFD Southeast	Ground water	VOCs	PTU	Air stripping with GAC	March 1998 – present	43.7 Mgal	78.7 kg
TFD South	Ground water	VOCs	PTU	Air stripping with GAC	June 1999 – present	43.0 Mgal	53.0 kg
TFD Helipad (PTU-10)	Ground water	VOCs	PTU	Air stripping with GAC	September 1999 – present	3.29 Mgal	32.9 kg
TFD Southshore	Ground water	VOCs	PTU	Air stripping with GAC	June 2000 – present	12.9 Mgal	30.5 kg

Table 4. Livermore Site treatment facility summary (Cont. Page 2 of 3).

Facility[a]	Media treated	Contaminants	Facility type	Technologies	Operating dates	Volume treated[b]	Mass removed[b]
TFD area (STU-10)	Ground water	VOCs	STU	GAC	March 2000 – present	1.08 Mgal	8.47 kg
TFE East	Ground water	VOCs	PTU	Air stripping with GAC	November 1996 – present	44.7 Mgal	65.4 kg
TFE Northwest	Ground water	VOCs	PTU	Air stripping with GAC	June 1998 – present	42.4 Mgal	12.5 kg
TFE North	Ground water	VOCs	PTU	Air stripping with GAC	December 1988 – present	19.6 Mgal	28.6 kg
TFE Southwest	Ground water	VOCs	MTU	Air stripping with GAC	June 2000 – present	6.03 Mgal	12.2 kg
TFE Southeast	Ground water	VOCs	MTU	Air stripping with GAC	March 2001 – present	5.25 Mgal	9.39 kg
TFE West	Ground water	VOCs	MTU	Air stripping with GAC	April 2001 – present	6.96 Mgal	28.4 kg
TFF	Ground water	FHCs; VOCs	Fixed	UV/oxidation; air stripping with GAC	February 1993 – September 1995	15.8 Mgal	7,280 kg
VTFF	Soil vapor	FHCs	Vapor extraction	Vapor extraction — GAC with steam regeneration	February 1993 – September 1995	42.5 Mft^3	23,000 kg
TF406	Ground water	VOCs	PTU	Air stripping with GAC	August 1996 – present	47.9 Mgal	9.68 kg
TF406 Northwest	Ground water	VOCs	GTU	GAC	July 2002 – present	N/A	N/A
TFG-1	Ground water	VOCs	GTU	GAC	April 1996 – present	17.4 Mgal	3.19 kg
VTF518	Soil vapor	VOCs	Vapor extraction	GAC	September 1995 – present	15,000 Kft^3	153 kg
TF518	Ground water	VOCs	MTU	Air stripping with GAC	January 1998 – June 2000	8.80 Mgal	1.15 kg
TF518 North	Ground water	VOCs	GTU	GAC	January 2000 – present	2.12 Mgal	2.63 kg

Table 4. Livermore Site treatment facility summary (Cont. Page 3 of 3).

Facility[a]	Media treated	Contaminants	Facility type	Technologies	Operating dates	Volume treated[b]	Mass removed[b]
TF5475-1	Ground water	VOCs, tritium	Catalytic Reductive Dehalogena-tion (CRD)	CRD	September 1998 – present	0.25 Mgal	3.34 kg
VTF5475	Soil vapor	VOCs, tritium	Vapor extraction	GAC	January 1999 – present	19,700 Kft^3	279 kg
TF5475-2	Ground water	VOCs	GTU	GAC	March 1999 – present	0.19 Mgal	0.57 kg
TF5475-3	Ground water	VOCs, tritium	CRD	CRD	September 2000 – present	0.03 Mgal	0.48 kg

Notes:

kft^3 = Thousands of cubic feet.

kg = Kilograms.

Mft^3 = Millions of cubic feet.

Mgal = Millions of gallons.

NA = Not applicable.

[a] Facility locations are shown on Figure 2.

[b] Totals through March 2002.

Table 5. System modifications.

Treatment Facility Area[a]	Issue	Resolution and/or Lessons Learned
TFA	Maintaining the Recharge Basin without adversely affecting any species	Worked with wildlife biologists to determine schedules for maintaining the Recharge Basin that will not adversely affect any local species. Also worked with the wildlife biologists to install an amphibian barrier around the western cell of the Recharge Basin to allow year-round maintenance within this cell.
TFA	Noise complaint	A neighbor claimed they could hear noise from the direction of LLNL. Atlhough the sound was probably not from TFA, a shroud was installed over the blower and discharge pump to reduce any noise.
TFA	Maintaining hydraulic capture and mass removal of the TFA offsite plume	Learned that the percolation cells of the Recharge Basin are less effective over time even with periodic maintenance, which leads to a reduced flow rate at TFA and reduced capture of the offsite plume. Periodic soil excavation from the bottom of the Recharge Basin cells and/or diversion of discharge water are being considered to improve TFA performance.
TFB	High operation and maintenance costs	With regulatory approval, switched from an ultraviolet oxidation system to a high-capacity air stripper to increase safety and reduce operation and maintenance costs by eliminating the handling of hydrogen peroxide.
TFC	Ion exchange not lasting as long as anticipated	The ion-exchange resin columns were placed prior to the air stripper to avoid (1) carbonate scaling of the resin due to carbonate precipitation after air stripping, and (2) interference with the Belsperse 161 (a sequestering agent that impedes carbonate scaling in the air strippers), which coated the resin beads.
TFD	pH changes during electro-osmosis	pH is difficult to control on the electrodes causing carbonate buildup and/or deterioration. Reversing the polarity about twice a week helps mitigate the carbonate buildup.
TFG	Chloroform discharge limits exceeded at TFG-1	Sampling between carbon canisters was being conducted to test for breakthrough, but only TCE was being analyzed since it was the only chemical above the drinking water standard in this area. It was discovered that chloroform is not treated as efficiently by the carbon and had earlier breakthrough than the TCE. New procedures were written and are in place to ensure that all VOCs are monitored between carbon canisters.

Table 5. System modifications (Cont. Page 2 of 3).

Treatment Facility Area[a]	Issue	Resolution and/or Lessons Learned
TFG	High frequency of GAC replacement at TFG-1	Because of the high frequency of GAC replacement, other carbon sources were evaluated. Vendors claimed that coconut carbon had a greater surface area and was more effective than regular GAC so it would last longer before it needed to be replaced. After testing and analysis, no improvement was observed in the carbon replacement frequency with TFG ground water. It was decided to return to using GAC which was equally effective and less expensive.
TF5475	Decreased flow in the CRD unit	Found that the CRD unit experienced biofouling (biological growth) over time. The CRD unit was removed and autoclaved to destroy the biological growth. Periodic flushing with bleach is now used as a preventative measure against further biofouling.
TF5475	Non-optimal remediation efficiency	Learned through experimentation that the water needs to be at 100% hydrogen saturation to obtain nearly 100% destruction of the TCE.
TF5475	Mixed hazardous and radioactive waste generation from vapor containing both VOCs and tritium	Learned that tritiated water has a higher tendency to adhere to the GAC than non-tritiated water. Also learned that heating the GAC allowed less water loading and more VOC loading so the GAC did not have to be replaced as often.
Overall	Lengthy downtime while cleaning air strippers	Learned that carbonate deposits can be removed by recirculating a citric acid solution through the air strippers for about 90 minutes. This saves the time and cost to dismantle and clean the air stripper, and returns the facility to operation more quickly.
Overall	Rusting and leaking of air stripper tanks	Over time, the welded seams on the stainless steel air stripper tanks began to rust causing the tanks to leak. Inspection by a metallurgist/welding specialist determined that the vendor did not use inert gas during welding, which resulted in a sub-standard welding process. The tanks were returned to the vender who now welds the air stripper tanks following the proper procedure.
Overall	Blowers failing on MTUs	The blowers were failing frequently on the MTUs. It was determined that the fan bearings were inadequate. Better bearings are now installed in the blowers.

Table 5. System modifications (Cont. Page 3 of 3).

Treatment Facility Area[a]	Issue	Resolution and/or Lessons Learned
Overall	High maintenance of computer-based controller	Used control software and a NT computer for the controller, which required upgrades with various software changes. Switched to an Opto-22 system programmable logic controller, which is more reliable and does not become obsolete.

[a] Treatment Facility areas are shown on Figure 2.

Table 6. Total project funding authorized by DOE during 1997–2002 for cleanup of the Livermore Site.

Fiscal year	Funding ($M)
1997	10.7
1998	9.3
1999	12.4
2000	10.9
2001	10.7
2002	10.2

Table 7. Estimated volume and mass of VOCs remaining in saturated HSUs in the vicinity of the Livermore Site.[a]

HSU	Estimated pore volume containing VOCs greater than 5 ppb (Mgal)	Estimated VOC mass dissolved in ground water (kg)
HSU-1A	0	0
HSU-1B	705	97
HSU-2	1,436	417
HSU-3A	239	205
HSU-3B	91	111
HSU-4	62	23
HSU-5	328	91
Total	2,861	944

Notes:

HSU = Hydrostratigraphic unit.

kg = Kilograms.

Mgal = Millions of gallons.

ppb = Parts per billion.

VOC = Volatile organic compound.

[a] Based on data through 2001.

Figures

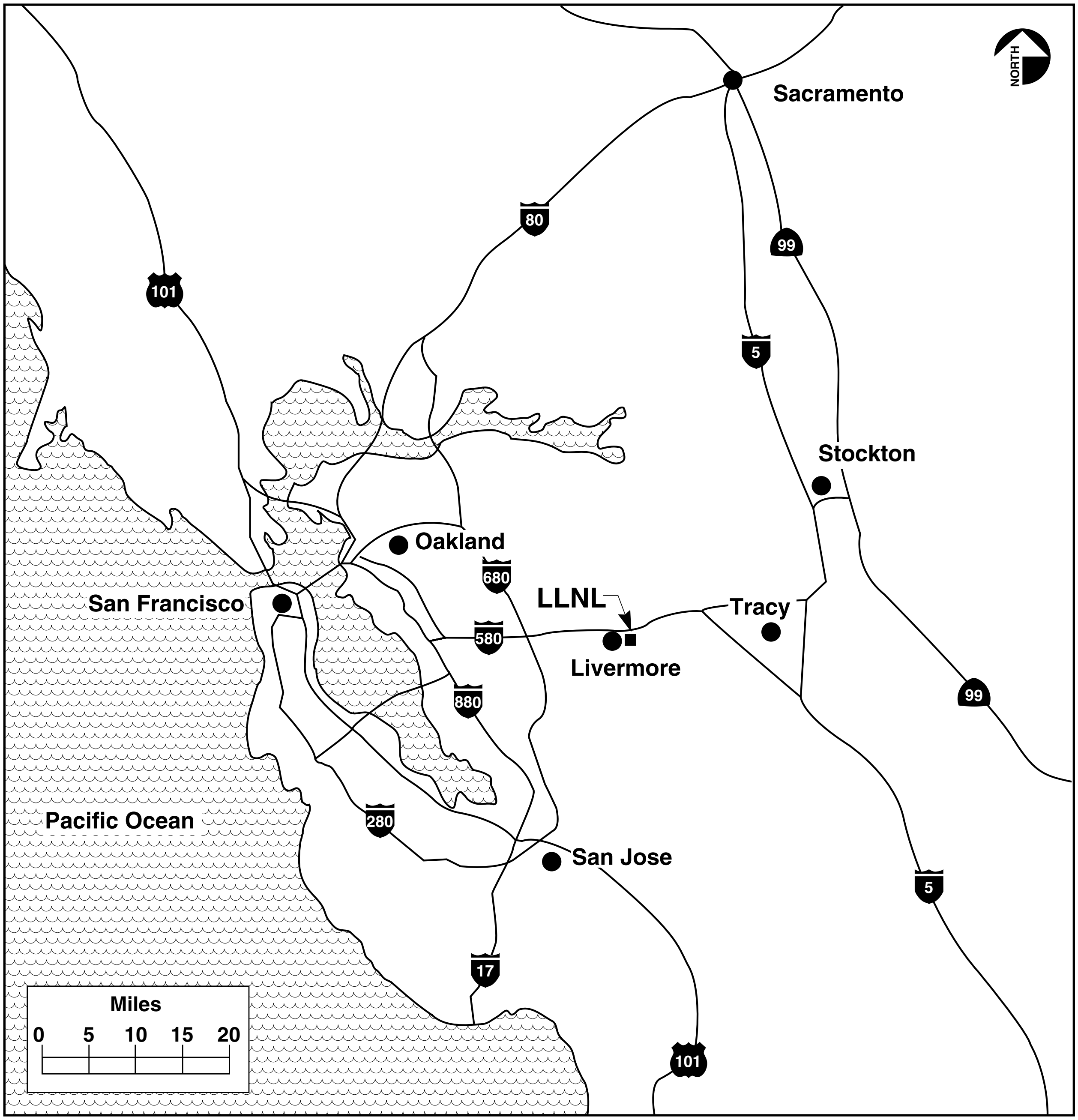

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Figure 1. Location of the LLNL Livermore Site.

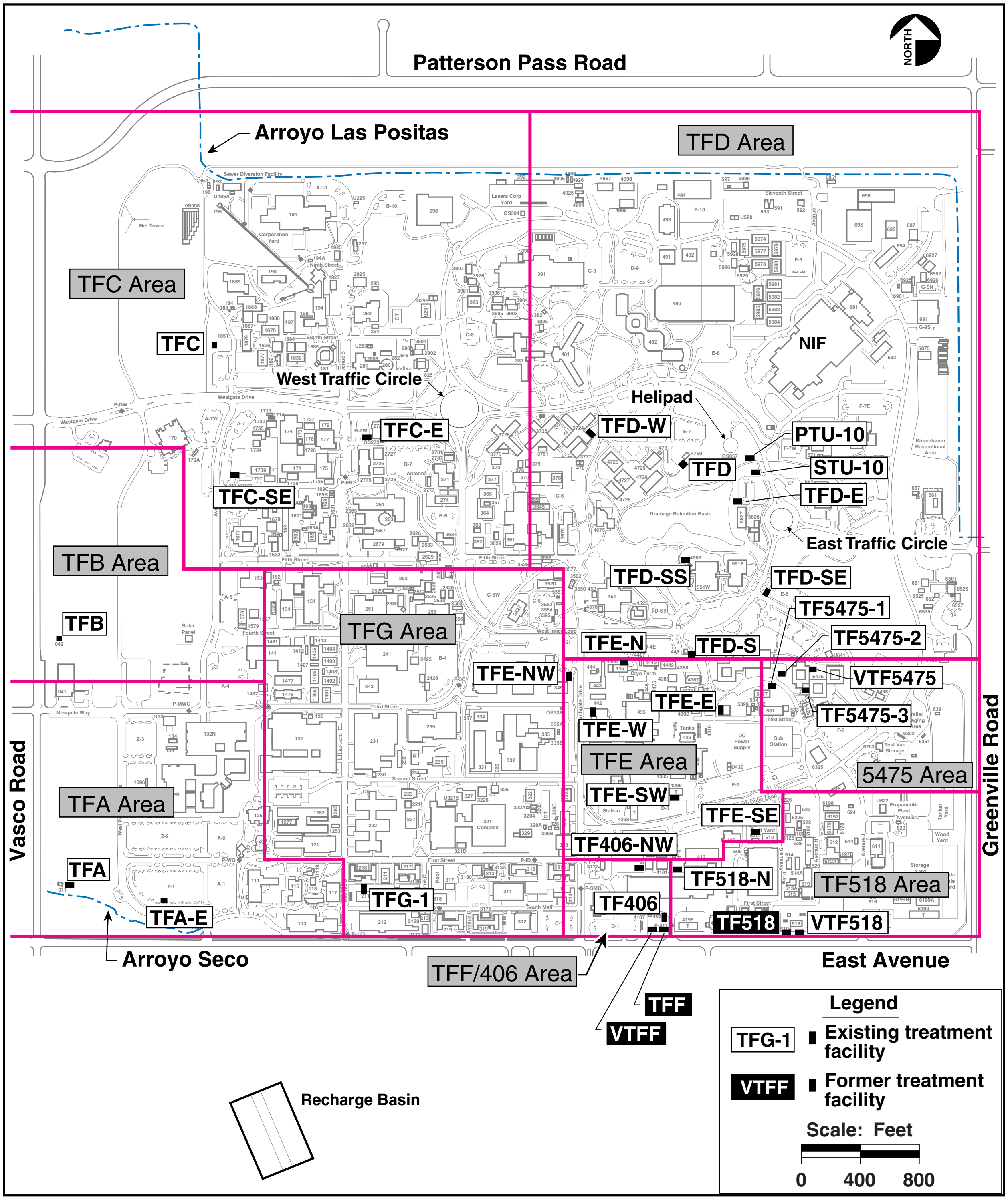
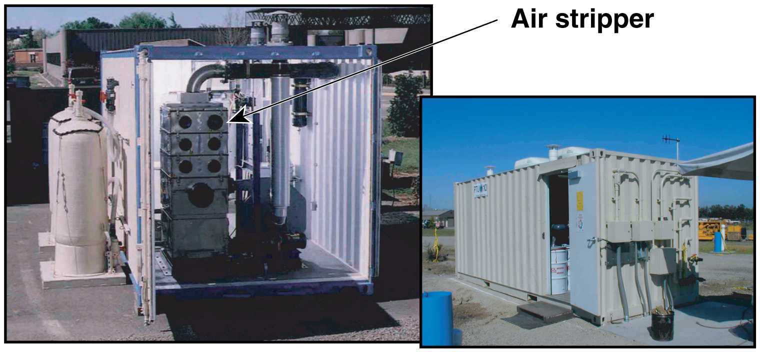


Figure 2. Treatment facilities and treatment facility areas at the Livermore Site.

Portable treatment unit

- Treats ground water flows up to about 45 gallons per minute.
- Uses an air stripper; the air stripper effluent vapor stream passes through granular activated-carbon to remove contamination.
- The facility is housed in a 20-ft long by 8-ft wide by 8-ft high cargo-type shipping container.

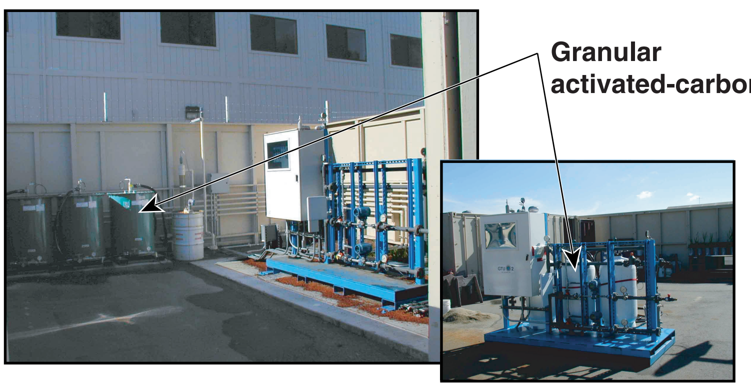


Miniature treatment unit

- Treats ground water flows up to about 25 gallons per minute.
- Uses an air stripper (half the capacity of a PTU); the air stripper effluent vapor stream passes through granular activated-carbon to remove contamination.
- The facility is 9-ft long by 4-ft wide, is weather resistant and attached to a skid.

Granular activated-carbon treatment unit

- Treats ground water flows up to about 45 gallons per minute.
- Ground water is pumped through the granular activated-carbon to remove contamination.
- The facility is 9-ft long by 4-ft wide, is weather resistant and attached to a skid.



Solar-powered treatment unit

- Treats ground water flows up to about 5 gallons per minute.
- Ground water is pumped through the granular activated-carbon to remove contamination.
- Uses solar panels and battery backup to operate.
- Adaptable for remote areas, or areas where electrical power is not available.
- The facility is enclosed in a 8-ft long by 4-ft wide by 4 1/2-ft high housing that is attached to a skid.

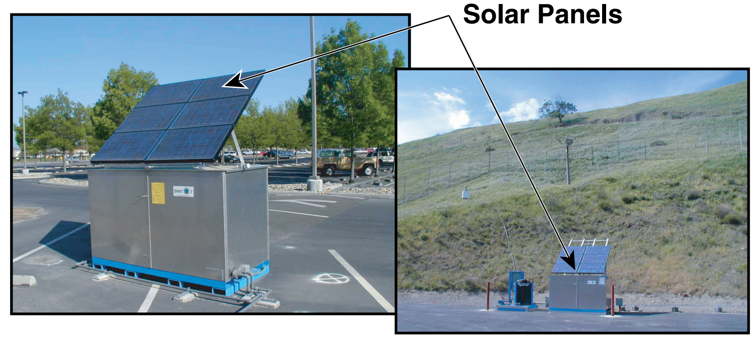


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Figure 3. Portable treatment units in use at LLNL.

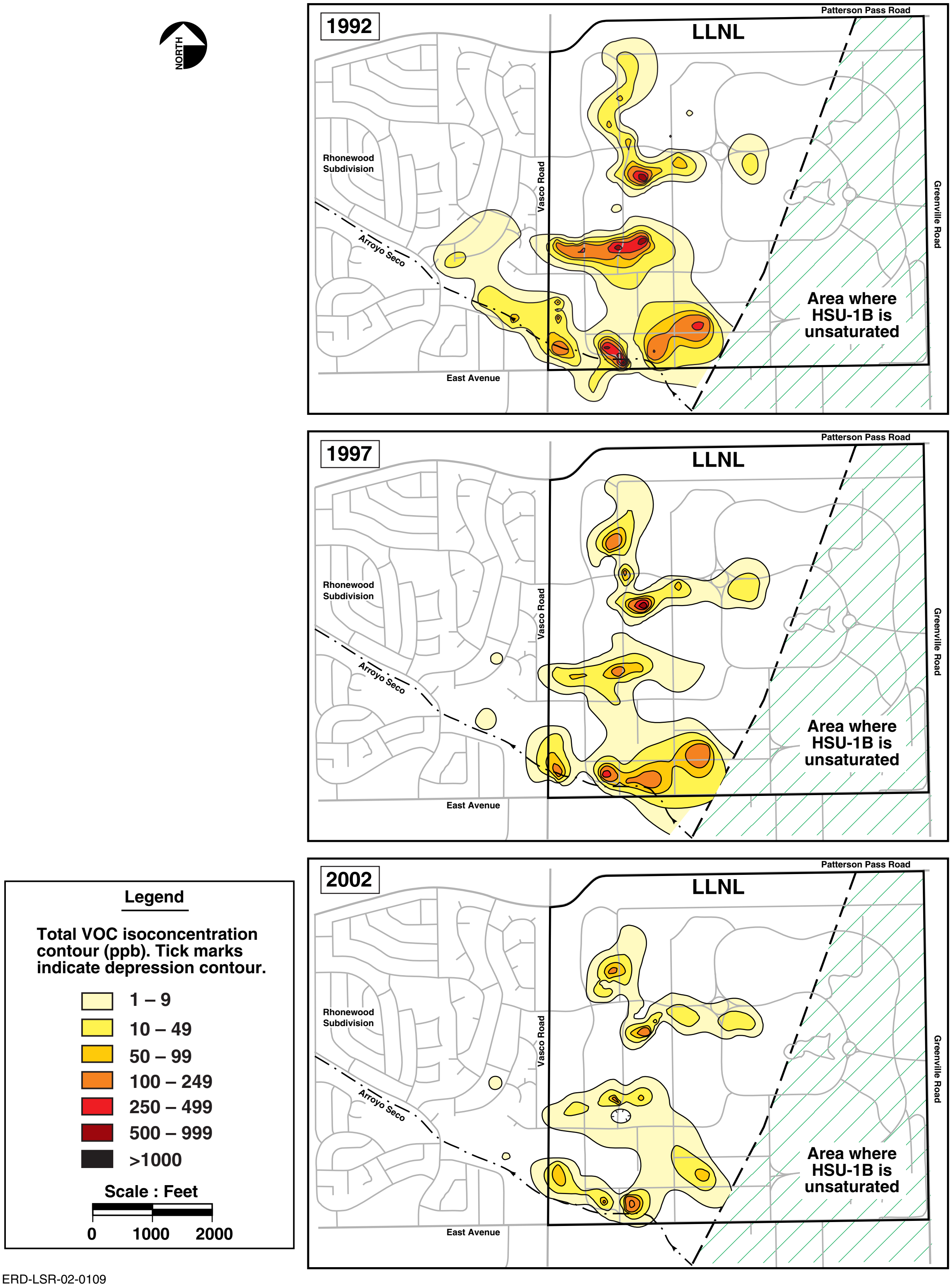

Figure 4. Time-series isoconcentration contour maps of total VOCs above MCLs for wells completed within Hydrostratigraphic Unit-1B (HSU-1B) for 1992, 1997, and 2002.

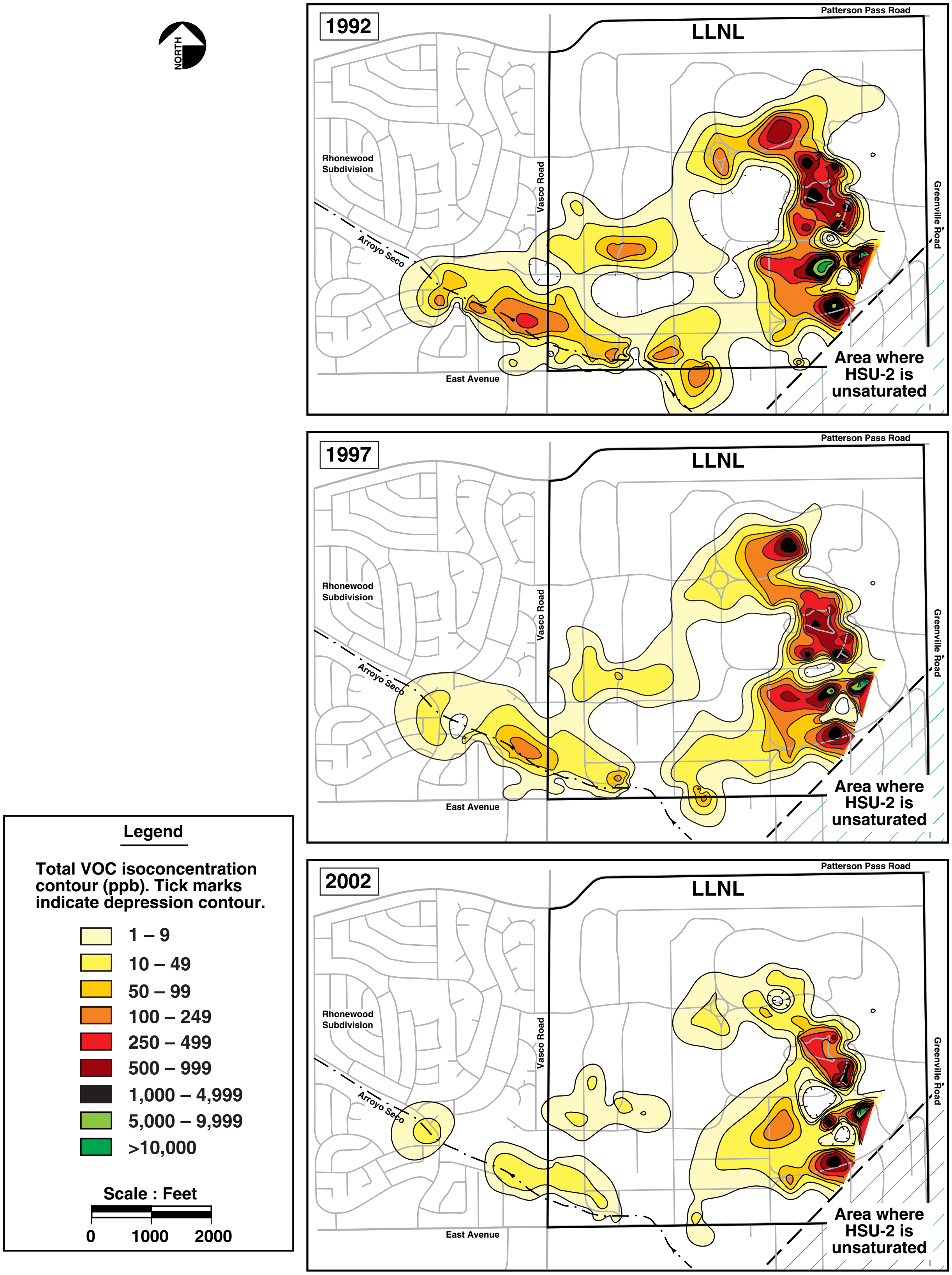

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Figure 5. Time-series isoconcentration contour maps of total VOCs above MCLs for wells completed within Hydrostratigraphic Unit-2 (HSU-2) for 1992, 1997, and 2002.

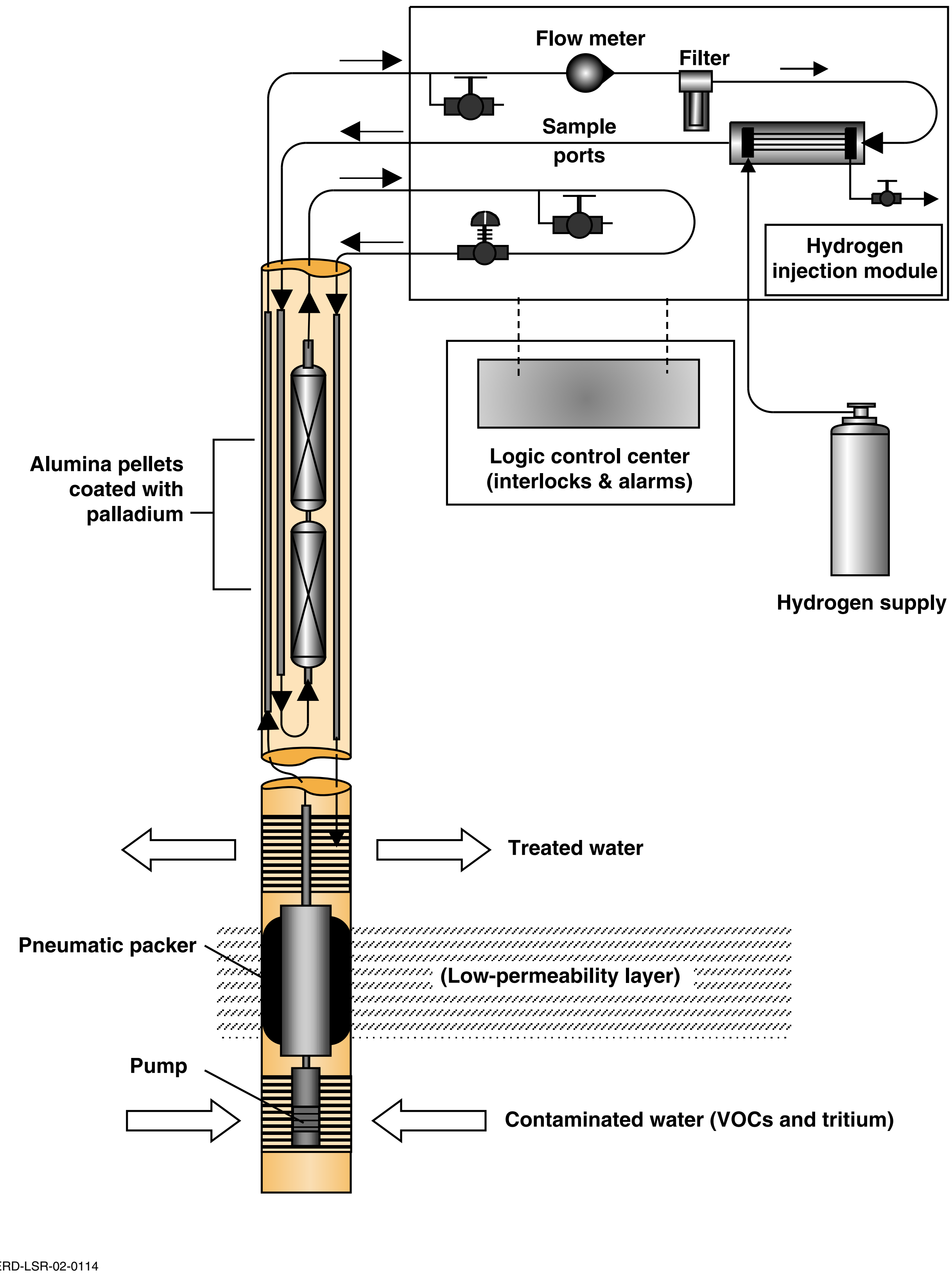

Figure 6. Downhole CRD unit deployment.

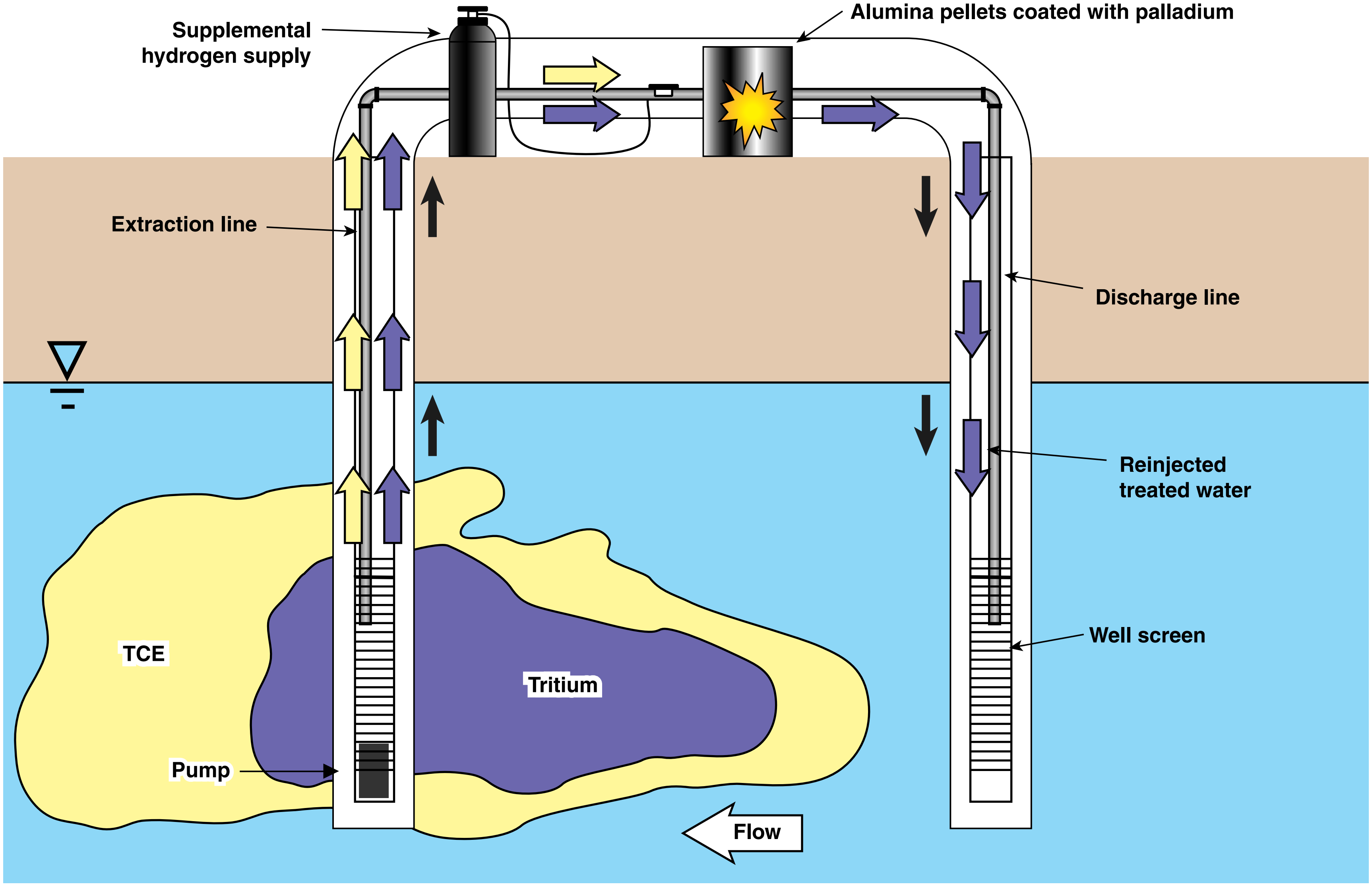

Figure 7. Aboveground CRD unit deployment.

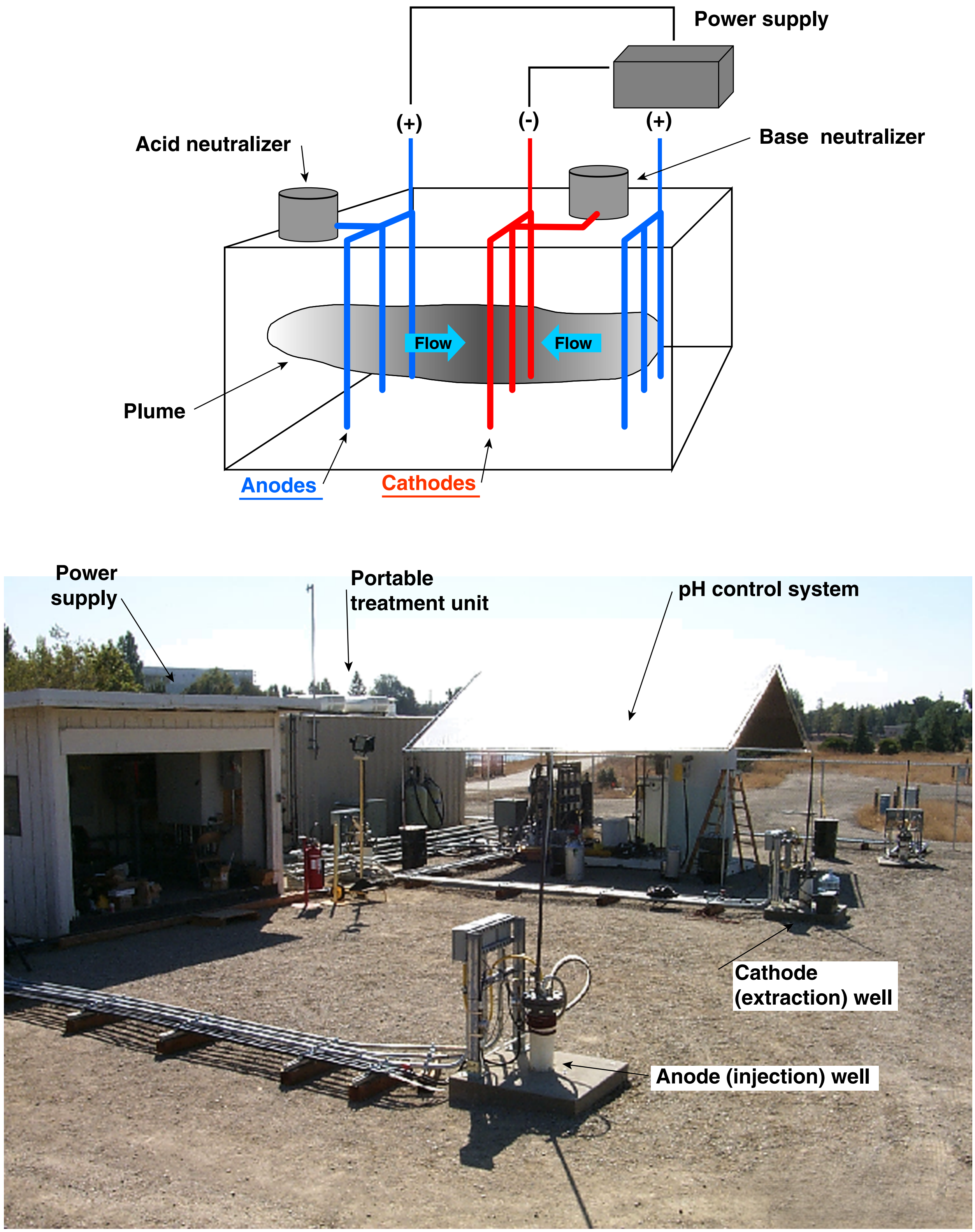

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Figure 8. Combined electro-osmosis/pump-and-treat system.

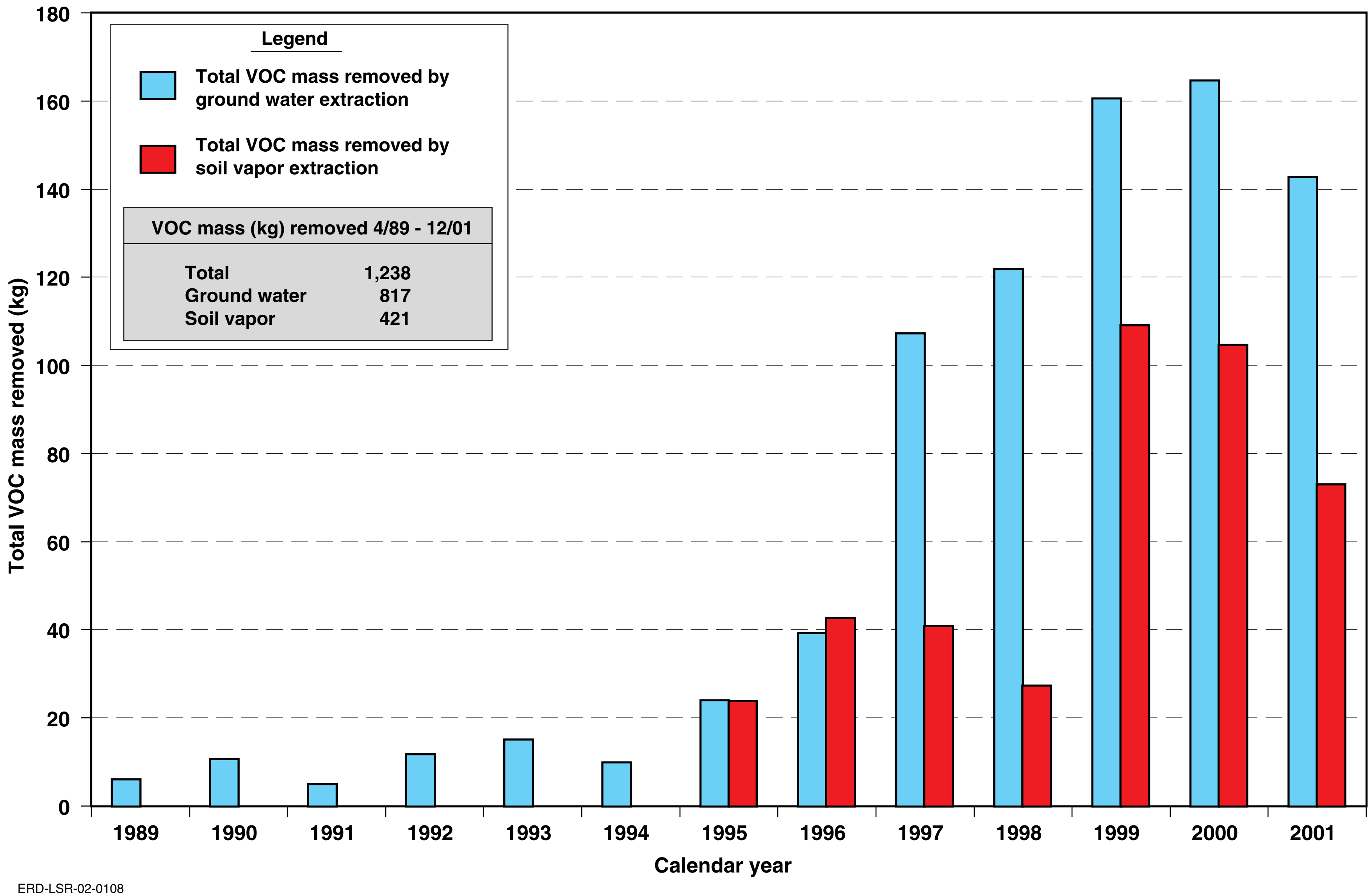

Figure 9. Total VOC mass removal in ground water and soil vapor from 1989 through 2001.

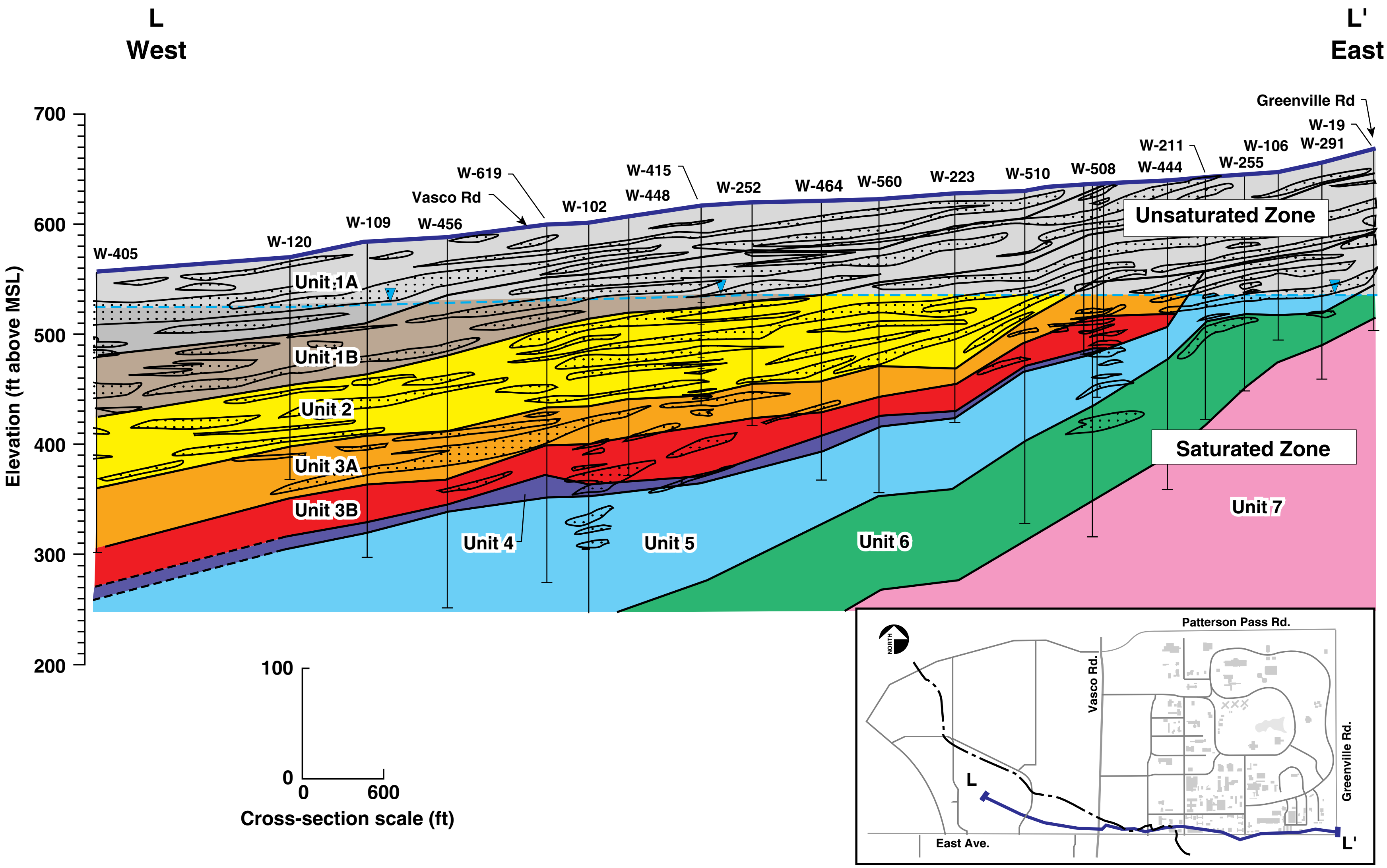

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Figure 10. Hydrostratigraphic units.